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13. ABSTRACT *(Maximum 200 Words)* The increased interest in high-speed naval ships has raised the design trade-offs between the three ship performance parameters of speed, mission payload, and range. These trade-offs were clearly identified as a result of the 1997 High Speed Sealift (HSS) Technology Workshop and the subsequent HSS Innovation Cell conducted at the Naval Surface Warfare Center Carderock Division (NSWCCD). The resulting HSS Technology Development Plan is summarized and highlights the limitations imposed on the near-term design solution space for high-speed naval ships; however, the Plan presents a comprehensive roadmap of the necessary investments in technologies critical to increasing these three ship performance parameters. Furthermore, increased interest in reducing the costs to develop and acquire naval ships has focused more attention on the time and costs to design and build new ships. A major initiative to address these apparent contradictory requirements is the recent establishment of the Navy's new Center for Innovation in Ship Design (CISD). Recent CISD Innovation Cell projects are briefly summarized. These projects clearly identify time dependent goals for the ship product technologies and the design and construction process technologies critical for new high-speed naval ships to meet the operators' vision of Naval Power 21.

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THE CENTER FOR INNOVATION IN SHIP DESIGN (CISD): SETTING THE HIGH-SPEED SHIP TECHNOLOGY ROADMAP FOR SEA POWER 21

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ABSTRACT

In the late 1960's and early 1970's, Admiral Elmo Zumwalt, then the Chief of Naval Operations (CNO) for the U. S. Navy, had a vision of a 100-knot Navy. As a result, considerable research was invested in developing high-speed craft, such as air cushion vehicles (ACV's), surface effect ships (SES's), and hydrofoils. However, political and economic pressures from a costly Vietnam War and an oil embargo forced cessation of research in high-speed naval ships.

Almost thirty years later with the explosion of the global economy and the increasing number of military conflicts in widely dispersed geographical locations, the U.S. Navy is under much greater pressure to maintain a forward presence in an expanding number of locations around the globe. The Navy's present CNO, Admiral Vern Clark, in a recent speech to the Naval War College, shared his vision for a new operational construct that he calls SEA POWER 21, as well as his thoughts on how the U.S. Navy needs to be transformed in order to meet the requirements of the new century. However, the Navy continues to experience decreased budgets for building new naval ships. The result is that the number of ships in our worldwide fleet is decreasing. These political and economic pressures are forcing the Navy to seriously consider much higher speed for the operational requirements of new ship designs and to acquire these new ships at lower costs.

The increased interest in high-speed naval ships has raised once again the design trade-offs between ship speed, mission payload, and range. These trade-offs have highlighted the limitations imposed on the design solution space for new naval ships, a manifestation of the lack of investment in technologies critical to increasing these three ship performance parameters. Furthermore, increased interest in reducing the costs to develop and acquire naval ships has focused more attention on the time and costs to design and build new ships.

A major initiative on the part of the Office of Naval Research (ONR) and the Naval Sea Systems Command (NAVSEA) to address these apparent contradictory requirements is the recent establishment of the Center for Innovation in Ship Design (CISD) at the Naval Surface Warfare Center, Carderock Division (NSWCCD). Recent "Innovation Cell" projects are summarized, including high-speed naval ship concept formulation (CONFORM) design studies conducted by NAVSEA's Future Concepts and Ship Design Group (SEA 05D) and NSWCCD's Total Ship Systems Directorate (Code 20). These projects clearly identify near-term and far-term goals for the ship product technologies and design and construction process technologies critical for new high-speed naval ships to meet the operators' vision of future naval warfare: **SEA POWER 21.**

1. SEA POWER 21: A NEW OPERATIONAL CONSTRUCT

In order to understand the renewed interest in high-speed naval ships, we as ship designers need to enter into a dialogue with naval operators and understand their vision for future naval warfare. The U.S. Navy's present Chief of Naval Operations (CNO), in a recent speech to the Naval War College, shared his vision for a new operational construct that he calls SEA POWER 21, as well as his thoughts on how the U.S.Navy needs to be transformed in order to meet the requirements of the new century.

In order to prepare for the wide array of threats facing our Navy, Admiral Clark stated in his SEA POWER 21 speech that we have to organize around a clear, concise, and powerful vision of what our Navy will provide in the years and decades ahead. He emphasized that the issue of the future readiness of the Navy has never been more important to discuss than it is today. Clarity of vision is critical to focus efforts and to coordinate support in this time of monumental change. At the heart of SEA POWER 21 are three required capabilities for the 21st Century:

Sea Strike, the ability to project offensive power;

Sea Shield, the ability to project defensive power;

Sea Basing, the ability to team with and provide enhanced support for joint forces around the world.

Sea Strike operations seize the initiative, disrupt enemy timelines, preempt adversary options, and ensure operational success. As we look into the future, the exciting changes that are taking shape include the incorporation of unmanned aviation systems, miniaturized munitions, and ship and submarine-launched, long-range sensors to guide weapons to targets.

Sea Shield is about projecting defensive power from the sea. As we look to the future, Sea Shield's littoral control capabilities will build upon a rich mix of manned and unmanned systems on, over, and below the sea. This combination of platforms, sensors, and weapons will assure access and provide the foundation of battlespace dominance. Sea Shield initiatives will assure access and protect the joint force ashore. Linked sensors and high-speed platforms will dramatically increase area clearance rates, including the location and avoidance of mines.

Sea Basing is about using the 70% of the earth's surface that is covered with water as a vast maneuver space to provide unprecedented support for joint forces. Pre-positioned ships will embark and debark ground forces and equipment at sea for very long-range assault missions. Platforms contributing to Sea Basing range from aircraft carriers to logistics ships. The land attack capabilities, for example, of the DD(X) destroyer and its associated family of ships will be a major addition to this effort, as will the next generation of amphibious assault ships, LHA(R), replacing the aging LHA class, and maritime pre-positioned ships, MPF(Future), to serve as afloat forward staging bases. Logistics ships, including high-speed sealift ships and vessels, will enhance on-scene endurance by providing needed supplies and rotational crews.

But, one might ask, will Sea Strike, Sea Shield, and Sea Basing capabilities be truly transformational? Will they usher in new ways of deterring conflict, new methods of waging wars, and new technologies leading to major increases in operational effectiveness? The answer to this important question is

dependent on how the Navy invests its near-term and far-term research and development funds. This vision of future naval warfare is ambitious, but previous generations have proven that aggressive innovation, experimentation, and investment in critical technologies are fundamental to meeting the challenges of an uncertain future. We live in such a time. Our security will require transforming the military to be ready to strike at a moment's notice in any corner of the world. Admiral Clark emphasizes that SEA POWER 21 is the way ahead for the U.S. Navy.

2. SEA TRIAL: FLEET EXPERIMENTATION THE HEART OF INNOVATION

History has shown that experimentation is key to innovation. One of the CNO's implementing initiatives to support development of greater operational capabilities is streamlining and integrating the Fleet experimentation process. The CNO initiative, called **Sea Trial**, puts the Fleet at the heart of innovation and provides a mechanism to more readily capture the fruits of their operational excellence and experimentation and to speed prototyping, enrich concept development, and more fully coordinate experimentation. A key organization for carrying out the Navy's transformation is the Navy Warfare Development Command (NWDC), which was established in June 1998 to develop new operational concepts, to plan and coordinate experiments to evaluate new concepts, and to develop doctrine. Two other organizations important to transformation are the Naval War College and the Chief of Naval Operations' Strategic Studies Group (SSG). The College conducts war games that test concepts and potential technologies. Its close working relationship with NWDC provides an avenue for new concepts to be further evaluated and integrated into experimental efforts. The SSG, comprised of senior Navy, Marine Corps, and Coast Guard officers, generates and analyzes innovative and revolutionary naval warfighting concepts and reports directly to the CNO.

There are at least two major reasons why the Navy has taken a more considered approach to its transformation. First, the Navy has not been building enough ships to recapitalize its existing force of roughly 314 ships. The time needed to acquire new ships and the continued constraints on the Navy's shipbuilding budgets necessitate a more fundamental look at its force structure and operations. Second, given the increased importance of littoral operations, greater urgency has been placed on developing new operational concepts and technologies needed to successfully operate in littoral areas. Littoral warfare operations extend from the shore to open ocean and inland from the shore over an extensive area that can be controlled directly from the shore.

Since March 1997, the Navy has conducted over ten fleet battle experiments. The experiments are assessed to determine which new operational concepts, tactics, and technologies prove workable and what follow-on experiments to pursue. Starting in September 2001, NWDC has been conducting a series of experiments to explore potential uses for high-speed ships, including amphibious lift, operational maneuver from the sea, mine warfare, maritime intercept, noncombatant evacuation, and helicopter operations. There are a number of major experiments with a variety of advanced vessels. They are briefly discussed in [1] and their characteristics are summarized below in Table 1.

TABLE 1 Characteristics of Experimental Vessels

Characteristics	UMOE Mandal KNM SKJOLD	Incat Jervis Bay	Austal III MEF	Incat 050 HSV-X1	Austal AutoExpress 72	Vosper RV TRITON	Kockums VISBY
Hull Type	SES	Catamaran	Catamaran	Catamaran	Catamaran	Trimaran	Monohull
Length (Overall)	47 meters	86 meters	101 meters	95 meters	72 meters	90 meters	72 meters
Beam (Overall)	13.5 meters	26 meters	26.7 meters	26.5 meters	17.5 meters	22.5 meters	10.4 meters
Draft	2.2 meters	3.5 meters	4.2 meters	4 meters	2.5 meters	3.2 meters	2.4 meters
Speed	55 kts	40 kts	37 kts	38 kts	40 kts	20 kts	38 kts
Lightship	203 tonnes	848 tonnes	1347 tonnes	945 tonnes	598 tonnes	1,136 tonnes	496 tonnes
Fuel (0% Margin)	36 tonnes	102 tonnes	156 tonnes	415 tonnes	59 tonnes	30 tonnes	93 tonnes
Payload (no fuel)	31 tonnes	320 tonnes	606 tonnes	368 tonnes	139 tonnes	176 tonnes	71 tonnes
Full Load Displacement	270 tonnes	1270 tonnes	2109 tonnes	1727 tonnes	797 tonnes	1,342 tonnes	660 tonnes
Payload Fract'n (WO Fuel)	12%	25%	29%	21%	17%	13%	11%
Range	800 nm	500 nm	1,076 nm	3,000 nm	608 nm	3,000 nm	1,500 nm
Engines	CODAG	4x Diesel	4x Diesel	4x Diesel	4x Diesel	2x Diesel	CODAG
Propulsor	Waterjets	Waterjets	Waterjets	Waterjets	Waterjets	FP Propllers	Waterjets
Installed Power	12,700 kW	28,337 kW	28,800 kW	28,784 kW	15,464 kW	4500 kW	18,600 kW

3. CENTER FOR INNOVATION IN SHIP DESIGN: A CULTURE OF INNOVATION

The key now is to accelerate this progress through a culture of innovation. However, due to the post-cold war draw-down of the Navy's in-house ship design capabilities, DOD acquisition reform initiatives, and changing ship acquisition approaches, the naval ship design community faces a number of challenges:

- Loss of experienced ship designers.
- Long gaps between new ship classes
- Aging workforce and shift of design source to industry
- Loss of direct fleet feedback to industry ship designers
- Loss of cross-class problem solving/prevention
- Lack of visibility of the Naval Ship Design Community

These challenges cannot be resolved by any one segment (government, academia or industry) but can only be resolved by collaborative efforts such as the Navy's new Center for Innovation in Ship Design (CISD). Funded jointly by NAVSEA and ONR, CISD is an interdisciplinary program devoted to the creation and development of breakthrough ship design technologies, processes and tools. CISD fosters collaboration within the naval ship design community to focus on a faster and more effective ship development process: *requirements, concepts, design, construction, certification, and operations.* CISD's program is based on an integrated approach to People, Knowledge and Innovation activities involving faculty and students from the Colleges of Naval Architecture /Marine/Ocean Engineering in cooperation with engineers and

scientists from NAVSEA, ONR, other Government activities, the U.S. Shipbuilding Industry, Ship Design Agents and professional societies such as the Society of Naval Architects and Marine Engineers (SNAME) and the American Society of Naval Engineers (ASNE).

CISD's mission is obvious: advance the theory and practice of ship design by combining the best ideas and experience of Industry, Government and Academia. Through the Center's People, Knowledge, and Innovation activities, participants explore new innovative ways to develop naval ships. The Center defines itself through partnerships and develops through its community connections to become an Industry-Government-Academia partnership. The Center grows as a research-best practice-collaborative learning partnership.

CISD's vision is clear: act as an enabling node linking a geographically distributed network of scientists and engineers highly skilled in ship design and its various sub-disciplines through the maintenance and operation of state-of the-art ship virtual prototyping facilities and the development and employment of collaborative engineering tools. As such, the Center infrastructure and staff provide the environment to quickly develop and assess new ship concepts as a function of emerging requirements and technologies using design tools that represent technologies at a physics-based level of characterization. The intent is to integrate models which are currently used or which will be developed by Academia, Industry, or Government into a ship virtual prototyping capability accessible by Government, Industry, and Academia.

CISD's program is built on the following three mission areas:

- **INNOVATION:** Drawing upon combined strengths of ONR, the NAVSEA "Corporation", Shipbuilding Industry and Academia in a collaborative team-learning environment for innovative Concept Formulation (CONFORM) whole-ship design studies.
- **KNOWLEDGE:** Identifying, learning, and integrating new technologies, design engineering methodologies, and management tools for a more innovative naval ship design development process.
- **PEOPLE:** Developing technically grounded ship design leaders for the naval ship design community.

4. INNOVATION CELLS: TRANSFORMING THE WAY PEOPLE THINK AND WORK

CISD formally recognizes the importance and value of innovation by providing a collaborative dedicated environment for creative team thinking across Industry, Academia and Government. Innovation cells are conducted at the Carderock Division with Navy, Academia, and Industry participation. The purpose of each cell is to develop a basic understanding of the influence of hull forms, signatures, materials, survivability, hydrodynamics, automation, propulsors, propulsion, payload, etc as a function of critical ship design parameters (speed, payload, range, displacement, etc) on producing total ship design concepts that are optimized to meet Navy requirements, operating modes and conditions, and total ownership cost.

A unique characteristic of Carderock's Innovation Cell (or team) approach is its many research laboratories that bring together interdisciplinary expertise from throughout the Navy to work on practical problems. This unusual attribute of the Carderock Division provides an unparalleled strength to CISD's Program. Working together through CONFORM teams, CISD can offer a learning paradigm that is rare

in industry and/or government today. Research and Development (R&D) is the bedrock of the Carderock Division, and CISD collaborates with a number of R&D programs, including the National Shipbuilding Research Program (NSRP), the Naval Postgraduate School (NPS) Wayne Meyer Institute for Systems Engineering (WMISE), the Virginia Advanced Shipbuilding and Carrier Integration Center (VASCIC), MIT's Center for Innovation in Product Development, Virginia Tech's Multi-disciplinary Analysis and Design (MAD) Center, NAVSEA's Hydro. Tech. Center, etc. CISD's program can draw on the best of these R&D activities, codify it in terms of new knowledge, apply it to ongoing ship designs, and impart it to the next generation of ship design leaders.

The innovation cells are fashioned after successful innovation processes in industry (skunk works) and the Carderock Division Innovation Center that has run over 20 cells in the last decade. Innovation cells produce hard products plus both tangible and intangible benefits to participating personnel. Hard products are physical means of long distance collaboration, new design tools, novel ship designs (which are matched to needs) and technology plans to guide knowledge development Tangible personnel benefits include: fostering communications within and across groups and communities, team members experience as integrators of ideas which the cell has developed; and experience in turning concepts into reality. Intangible benefits relate to training and experience building: view of the big defense picture; understanding a systems approach; working across communities; developing interpersonal skills in a team environment; developing networks of contacts in broad disciplines; and learning to create a vision and "market" that vision.

Innovation is really knowledge plus creativity plus implementation. Knowledge of current technology and design processes defines the unresolved problems of what exists already. Creativity involves doing differently things that are currently done the standard way, as well as doing new things. Implementation depends on collaboration across the stakeholder community, building internal and external coalitions, communities of practice, fostering consensus on proposed new approaches with mentors and workshops. *The process has the effect of fundamentally transforming the way people think and work.*

5. CISD INNOVATION CELLS: INNOVATION IN PRODUCT AND PROCESS

To realize transformational innovations in our ship designs, as well as transformational innovations in the entire ship development process, CISD utilizes Ship Concept Formulation (CONFORM) Innovation Cells or multi-disciplinary teams involving Government, Academia, and Industry. This approach is based on NAVSEA's positive experiences on specific ship programs in collaborating with shipbuilders and academia in learning and experimenting with new product development tools, processes and technologies. These Innovation Cells in the past produced new design tools, innovative concept designs, technology development plans and process innovations. Although these were excellent learning experiences that contributed to "winning" ship designs and successful ship acquisitions, they were, non-the-less, ad-hoc. To sustain such innovations through a culture of innovation required building a collaborative enterprise like CISD. The following is a brief summary of activities of recent CISD Innovation Cells:

Small,Fast Combatant Innovation Cell. Created database of existing small (300-5000T) high speed vessels. Spreadsheet parametric models for high-speed monohulls, catamarans and trimarans were used to assess the impact of different technologies on design parameters and design space to achieve ship concepts with a high degree of confidence. Defined a roadmap of near-term (available in 5 years) technology investments required for small, high-speed Naval ships. Extensive use was made of

technology projections made in 1997 at the High Speed Sealift Technology Workshop, which is described in more detailed in the following sections.

Sea-Based Operations Innovation Cell. Developed a roadmap of key technologies and other technical challenges needed to fully exploit system concepts and how they must be matured and then integrated into total (ship) system designs.

Modeling & Optimization Innovation Cell. Mapped the overlap between needs and possibilities in M&O for naval engineering and developed a short list of basic research thrusts with optimal payoff for naval design applications. Developed a five-year research plan.

TIES-UTE Design Tools Innovation Cell. Evaluated design trade space for existing high speed, small combatant concepts using Technology Identification, Evaluation and Selection (TIES) and Unified Tradeoff Environment (UTE) tools.

Multi-disciplinary Design Optimization (MDO) Innovation Cell. Quantitative methods for measuring mission effectiveness were developed for an ongoing ship design. Consistent methodology was developed for multi-objective decisions based on dissimilar objectives: mission effectiveness, cost, and risk. An efficient and robust method to search the design space for optimal design solutions was applied to ongoing trade studies.

Ship Design Approval Process Innovation Cell. Navy stakeholders developed a Design Approval Process that ensures better design decisions, increases the ease of passing major DOD acquisition milestones, and ensures the Navy enters into a shipbuilding contract with greater confidence in achieving program requirements of performance, cost and schedule.

Capturing Producibility and (VFI) Earlier in Ship Design Innovation Cell. Focus on identifying how Producibility and Vendor Furnished Information (VFI) can be captured earlier in the Ship Design Process; draw lessons learned from the best commercial product development practices.

Laser Welding/Lightweight Structures Innovation Cell. Propose to develop lightweight structural design concepts for early stage ship design, which will realize the advantages of laser welding (reduced weight and cost).

6. THE CISD MODEL: HIGH-SPEED SEALIFT (HSS) INNOVATION PROCESS

The CISD mode of operation is based on the proven innovation process developed for the Sealift Ship Program. It includes community-wide (enterprise-wide) workshops to identify and gain consensus on critical needs followed by multi-disciplinary Innovation Cells (teams) to develop program plans for satisfying the critical needs. Utilizing a Total Ship Systems Engineering (TSSE) approach, NAVSEA developed a collaborative process with Industry, Academia, Navy and other government organizations to help define the next generation of sealift ships.

HSS Community-Wide Workshop (extracted from [2]). A High-Speed Sealift Technology Workshop [2], sponsored jointly by the U.S. Transportation Command (TRANSCOM), the Center for the Commercial Deployment of Transportation Technologies (CCDOTT), U.S. Maritime Administration,

U.S. Army, and U.S. Navy, was held at the Naval Surface Warfare Center, Carderock Division in October 1997. This Workshop examined the possibilities offered by technology to enhance the transport performance of high-speed (40-100 knots) commercial and military sealift ships in order to help define realistic future mission capabilities and to focus the subsequent design and cost studies necessary to enable technology investment decisions. The results of this process clearly identify what the Navy needs to do to implement the high-speed sealift part of SEA POWER 21.

The Workshop solicited expert opinion to address technology projections in six critical technologies; namely, Ship/System Concepts, Hull Forms and Propulsors, Propulsion Plant, Cargo Onload/Offload and Stowage, Materials and Ship Structures, and Shipbuilding and Manufacturing. Economic considerations were not introduced at this stage since the initial focus was on determination of technological feasibility without regard to cost of development or commercial viability. The Workshop, combined with subsequent ship concept studies, developed predictions of expected levels of sealift capability associated with different technologies. Mission parameters of speed, range, and payload were related to ship design characteristics of displacement, installed power, cargo weight, and fuel weight. These were subsequently published in 1998 [3-5].

Figure 1 represents the maximum mission performance associated with the technology projections made at the Workshop. It shows that significant high-speed sealift capabilities are scientifically possible using such technology projections in the near-term and the far-term, where the near-term relates to technology that could be available in five (5) years and the far-term, ten (10) years. Full realization of the sealift capabilities shown in Figure 1 requires engineering development, particularly in packaging propulsion technology, advanced hull forms, and advanced materials and structures.

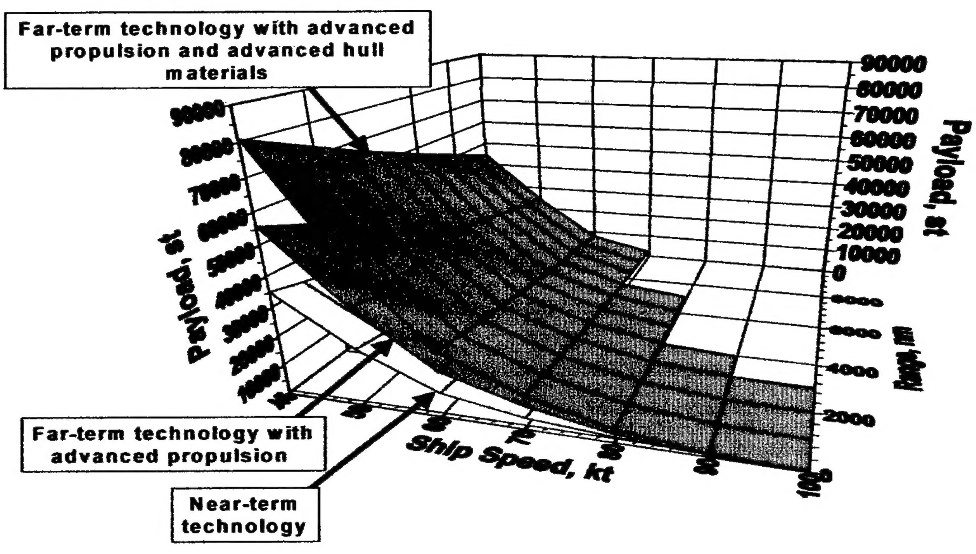

Figure 1 Predicted Impact of Technology on Speed/Payload/Range

HSS Innovation Cell (extracted from [2]). The results described below are taken from the outstanding technical work performed by the High-Speed Sealift Innovation Cell, under the leadership of Dr. Colen Kennell, at NSWCCD from May 2000 through August 2001. Another major contributor was Mr. Christopher Broadbent of the U. K. Ministry of Defence. The purpose of the project was to define the technology investments required to enable development of the high-speed commercial and military ships needed to provide realistic future mission capabilities.

Following the HSS Workshop in 1997, an Executive Steering Committee (ESC) of Flag and General officers was formed to co-ordinate U.S. Army, TRANSCOM, and U.S. Navy HSS efforts. A High-Speed Sealift Innovation Cell was chartered by the ESC to take this technology guidance and convert it into concept ships to examine whole-ship implications of the technologies. The main aim of the Innovation Cell was to derive a Technology Development Plan (TDP) on the basis of demonstrable need and platform performance. Technologies were classed as near-term (could be available in 5 years) and far-term (could be available in 10 years).

Experienced military operators served as action officers for the ESC and provided nine hypothetical military and commercial missions. Sensitivity studies around range, speed, and payload generated another additional six design points. In addition to mission parameters of speed, range, and payload, each mission description included a technology characterization. The process that the Innovation Cell and the action officers followed is shown in Figure 2 and was critical to the successful integration of technology development plans and new ship product strategies.

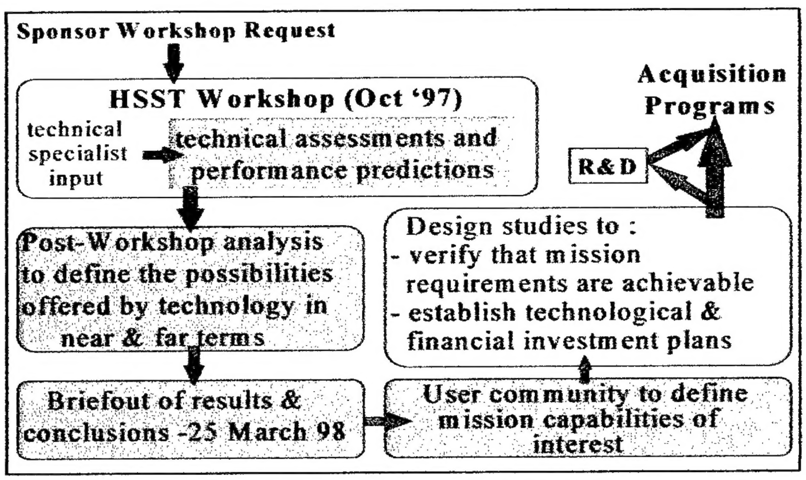

Figure 2 Process for Integrating Technology Development and New Ship Product Strategy

Included in the mission set are both short-range coastal commercial/intra-theater military missions as well as long-range trans-ocean commercial/inter-theater military missions. Speeds for the short-range missions were relatively low (40-50 knots). Higher speeds (55-70 knots) were specified for the longer ranges associated with the inter-theater/trans-ocean missions. Payloads varied from a few hundred tonnes for the least demanding intra-theater mission to 12,000 tonnes for the most demanding inter-theater missions. The missions are summarized in Table 2. The intention was to cover as many vessel types as could reasonably be considered contenders for each mission. Monohull, catamaran, trimaran and Surface Effect Ship (SES) designs were produced for each of the missions. Other high-performance ship concepts were not included either because the speed, range, or payload parameters of interest were judged to be incompatible with the performance attributes of those concepts or because the available technology base would not support development of the required designs.

TABLE 2 Summary of High-Speed Sealift Missions

	Shuttle Ship 1a	Shuttle Ship 1b	Intra-Theater Support Ship 2a	Intra-Theater Support Ship 2b	Coastal Commercial Ship 3	Trans-Ocean Commercial Ship 4a	Trans-Ocean Commercial Ship 4b	Inter-Theater Ship 5
Average Speed (knots)	40	45	40	40	50	50	60	40
Full Performance Wave Height (m)	2.4	2.4	2.4	2.4	2.4	4	4	4
Range (nm)	1,250	1,250	800	1,200	1,500	4,000	4,000	5,000
Payload (mt)	1,497	1,497	454	454	1,500	7,500	7,500	5,445
Ramp Requirements	y	y	y	y	n	n	n	y
Total Crew	20	20	20	20	20	30	30	30
Structural Technology	current	current	current	current	current	far	far	near
Waterjet Technology	current	current	current	current	current	far	far	near
Prime Mover Technology	current	current	current	current	current	far	far	near

	Vision Ship 70 knots 6a	Vision Ship 60 knots 6b	Vision Ship 55 knots 6c	Vision Ship 5,000 st 7a	Vision Ship 7,500 st 7b	Intra-theater Ship 8	Logistics Ship 9
Average Speed (knots)	70	60	55	55	55	40	50
Full Performance Wave Height (m)	4	4	4	4	4	2.4	2.4
Range (nm)	5,000	5,000	10,000	8,700	8,700	800	1,000
Payload (mt)	4,537	11,797	11,797	4,537	6,806	1,312	726
Ramp Requirements	y	y	y	y	y	y	y
Total Crew	30	30	30	30	30	20	20
Structural Technology	far	far	far	far	far	near	near
Waterjet Technology	far	far	far	far	far	near	near
Prime Mover Technology	far	far	far	far	far	near	near

Development of concept designs for each of the hull form types to a uniform standard was a priority. Common design standards, margins, manning assumptions, and weight algorithms were adopted where practical and appropriate. A common philosophy for loading, stowing, and unloading cargo was used. In particular, technology projections from the HSS Technology Workshop for structures and materials, gas turbines, reduction gears, and waterjets were combined with additional technical information to produce a common basis for these technologies in the designs. Representative ship concepts for each of the four hull form types are illustrated in Figures 3 to 6. The overall proportions of the different ship types, arrangement of cargo spaces, and machinery plant concept are evident from the figures.

The resulting concepts varied from small intra-theater ships displacing a few thousand tonnes to inter-theater ships with displacements in excess of 50,000 tonnes. Wide variations in the amount of installed power resulted from this size variation and the speeds required. Ship displacements for the concept designs are summarized in Figure 7. These concept designs were the basis for a technology development plan.

The capabilities needed from each of the technologies to produce these designs were compared with the technical state-of-the-art for those technologies to define the necessary near-term and far-term technology developments. Estimates of the time to develop and rough-order-of-magnitude development costs were made for each of the technologies based on a variety of factors including experience with development of similar technologies, engineering estimates, vendor data, and cost models. The goal is to bring the individual technologies to a level of maturity sufficient to lower risk to levels appropriate to ship design and construction.

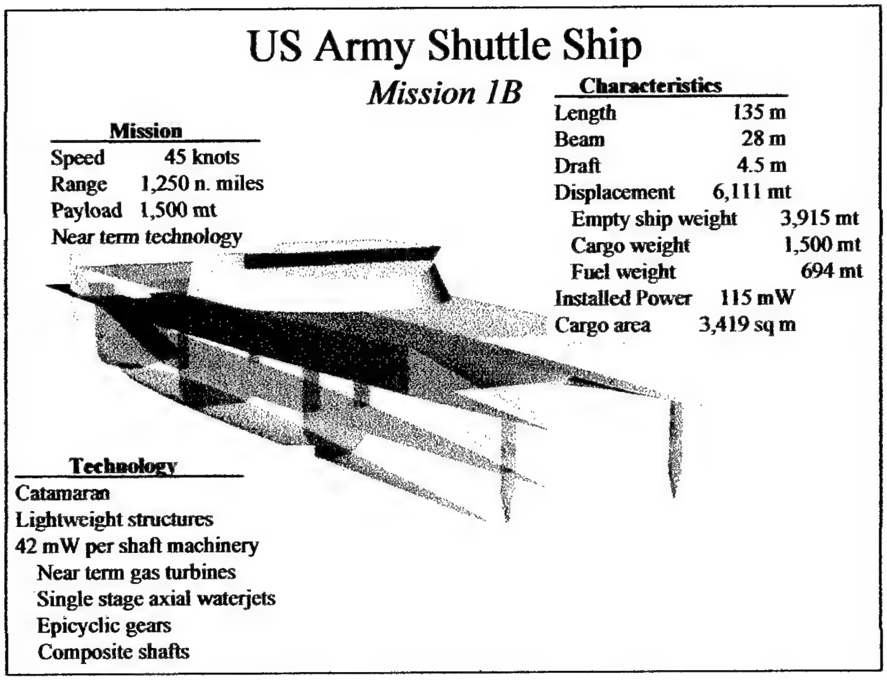

Figure 3 Representative Near-Term Technology Intra-Theater Catamaran

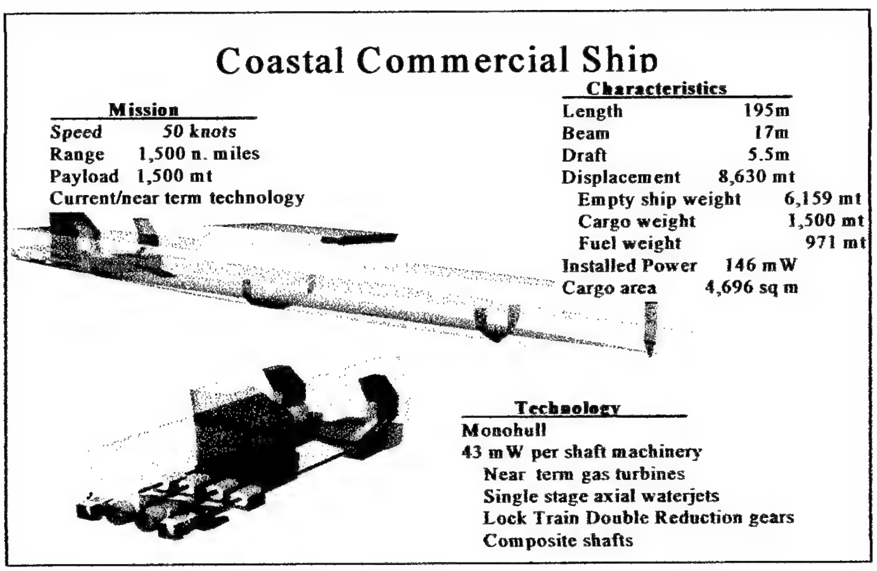

Figure 4 Representative Near-Term Technology Intra-Theater Monohull

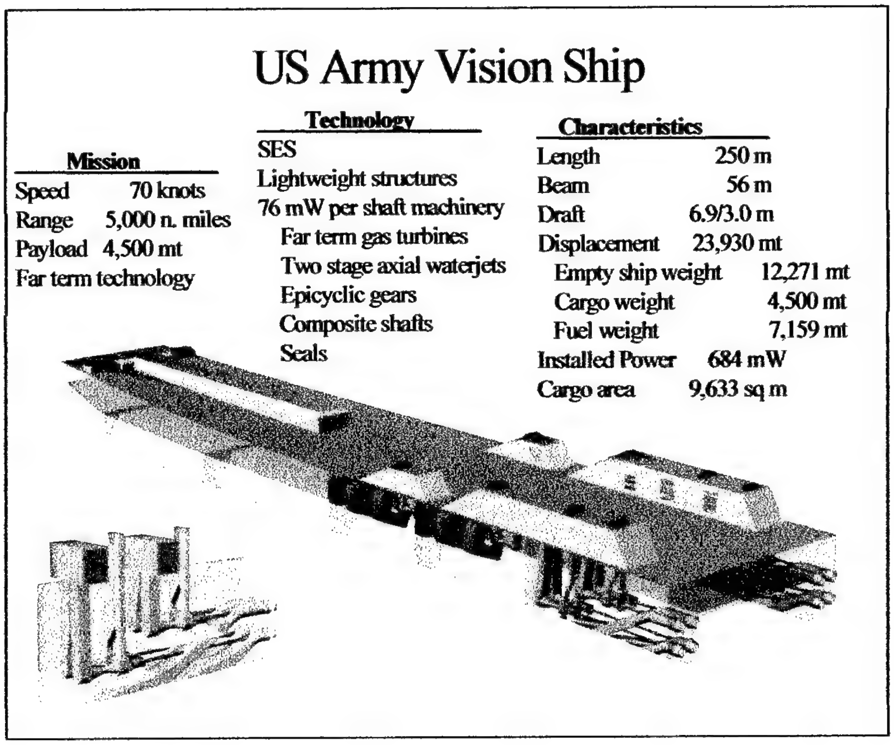

Figure 5 Representative Far-Term Technology Inter-Theater Surface Effect Ship

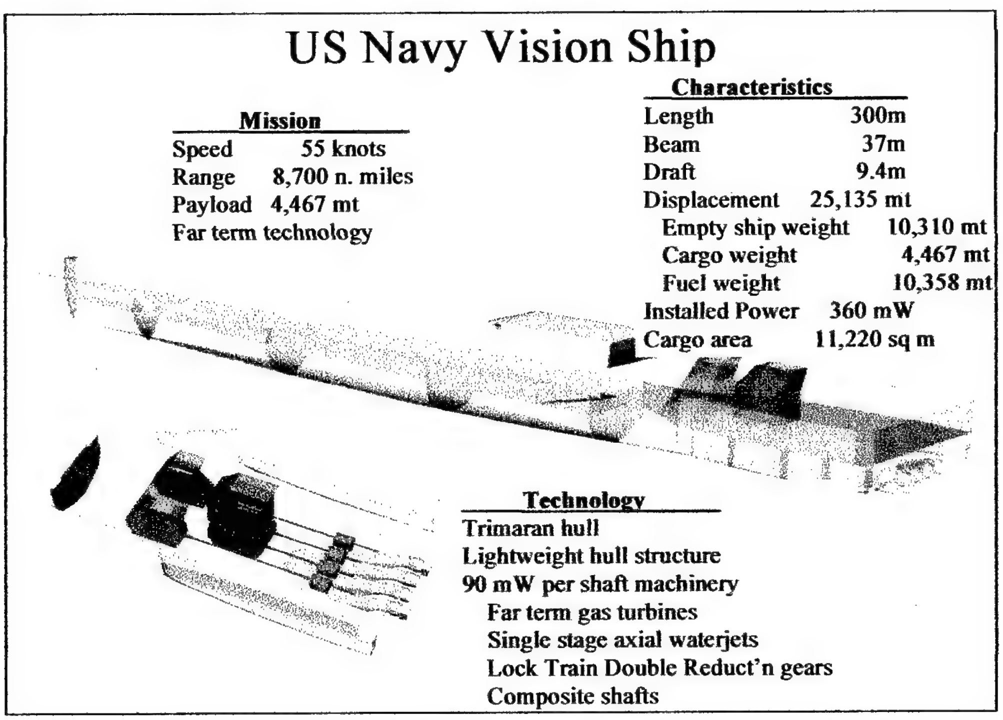

Figure 6 Representative Far-Term Technology Inter-Theater Trimaran

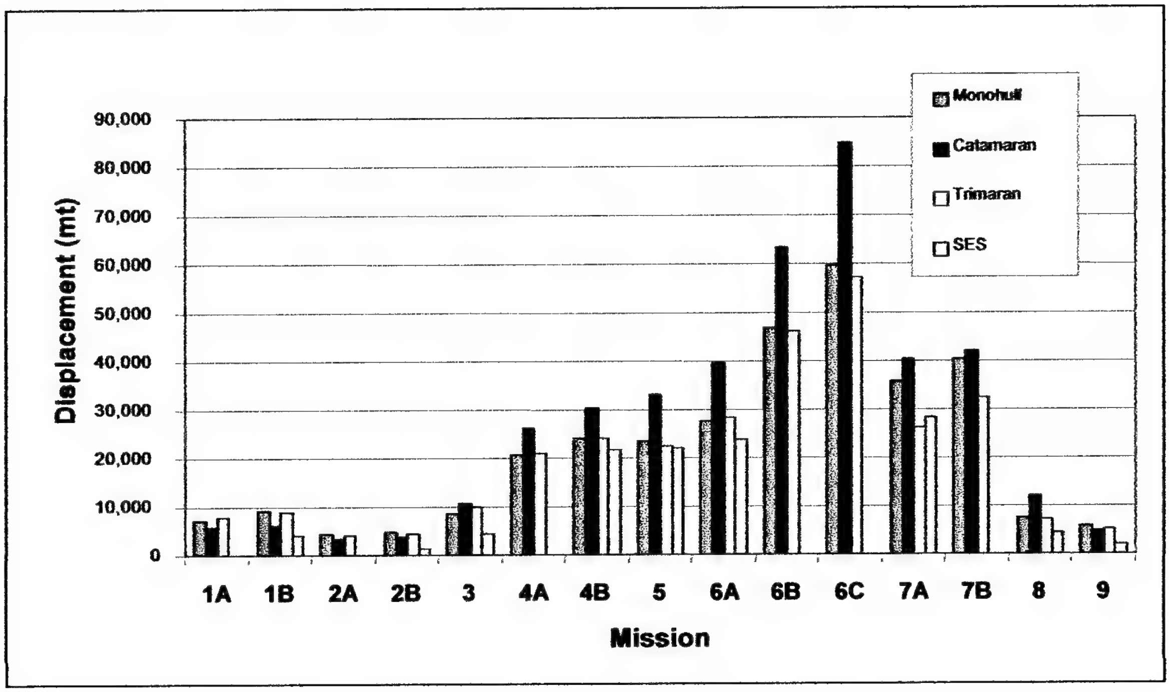

Figure 7 Full-Load Displacement of HSS Designs

7. HSS CRITICAL HULL FORM TECHNOLOGIES (EXTRACTED FROM [2]).

The choice of hull form technology has a particularly large impact on requirements for other technologies. For example, development of far-term SES hulls requires development of SES-peculiar lift fan and seal technologies. Alternately, monohull and trimaran hulls require development of locked train, double reduction (LTDR) gear technology, SES hulls require epicyclic reduction gear technology development, and catamarans require a mix of epicyclic and LTDR technologies. Since choices such as these cannot be made with certainty prior to commitment to specific long-term objectives, the redundancies have been identified and retained at the individual technology level. However, it is unlikely that the full matrix of technologies will need to be developed.

Monohull. Achieving the speed and range requirements identified for near and far-term monohulls requires hulls that are much more slender than hulls used on traditional designs. Slenderness parameters of these advanced hulls are well beyond the existing technology base. As a result, expansion of the technology base is required to allow reliable prediction of vital design characteristics such as sea induced loads, resistance, powering, seakeeping, and maneuvering. The hydrodynamic integration of high-power waterjets into these slender hulls is of particular importance to minimize installed power, minimize fuel consumption, and assure reliable operation in representative sea conditions. The needed technology includes extension of analytic models and computer programs to address the slender hulls and higher speeds as well as comprehensive model test data. The size-speed relationship of HSS far-term monohulls is compared with representative conventional ships in Figure 8. The figure illustrates the significant increase in speed required for these far-term HSS missions.

Slenderness and high speed also have pronounced effects on structural design and performance. Hull girders for the hydrodynamically slender hulls are also structurally slender. Sensitivity of powering performance to weight, coupled with the magnitude of structural weight fractions for HSS designs, results in low structural weight being a design priority. Furthermore, high speeds are expected to result in significant slam loads in realistic seas. Consequently, structural loads and reactions to the loads such as slam induced whipping, both vertical and lateral, are expected to be of critical importance for slender high-speed monohulls. The resulting high frequency, large amplitude accelerations are expected to have significant effects on cargo, crew, and hull fatigue life.

Trimaran. The HSS trimaran hull forms are essentially slender monohulls with very small side hulls added to provide buoyant stabilization. HSS trimaran side hulls typically provide only 2% of total buoyancy. While the side hulls add complexity, most technical aspects of trimaran center hulls may be viewed as essentially indistinguishable from the slender monohulls discussed above. Consequently, the extensive monohull technology base is also applicable to trimaran center hulls. Similarly, the technology extensions resulting from increased slenderness of HSS monohulls are also required for trimarans. Additional trimaran specific extensions are required to address side hull related issues such as resistance, flow characteristics, seakeeping, loads, structural response, and maneuvering and control of the combined side hull and main hull. While these trimaran-specific technology requirements add complexity, the overall effort is of the same scope and magnitude as that of the monohull. The size-speed relationship of HSS far-term trimarans and monohulls is compared with representative conventional ships in Figure 8.

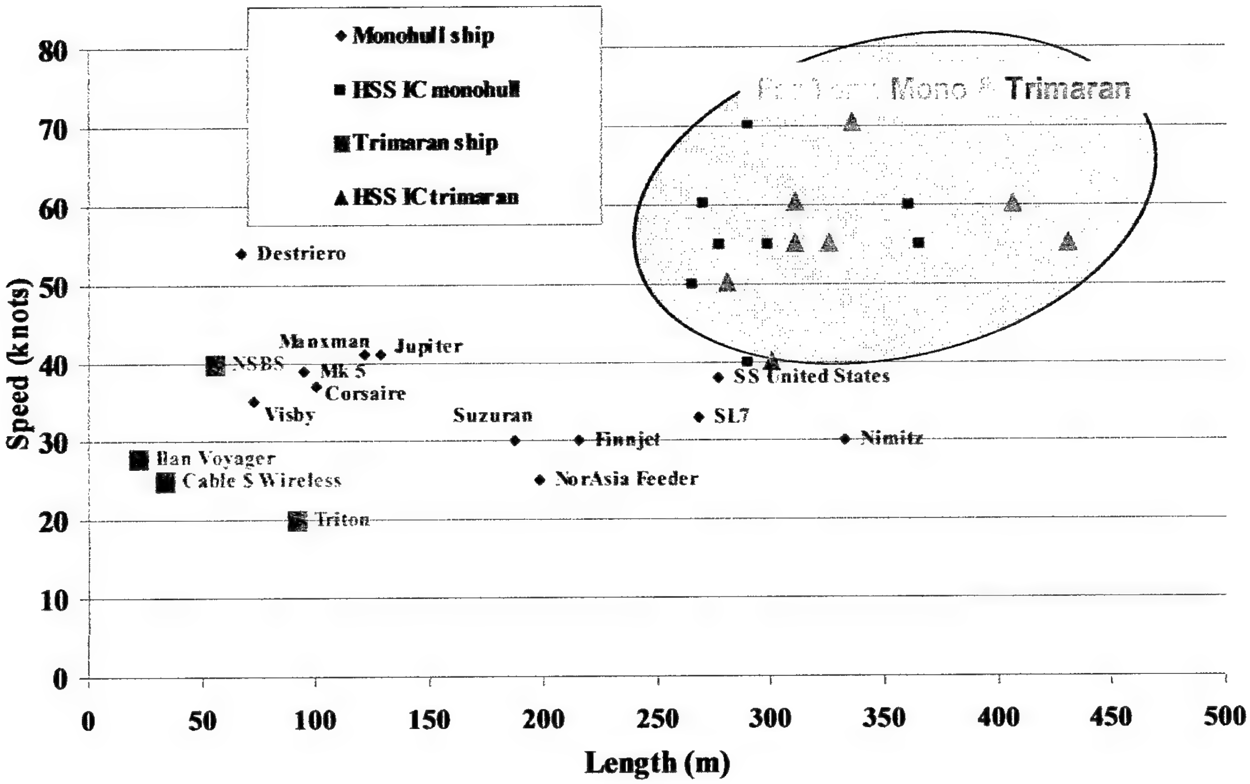

Figure 8 Monohull/Trimaran Technology

As with the monohull case, a significant increase in speed is required for these far-term HSS missions. Speed requirements for most near-term missions are much closer to demonstrated capability.

Catamaran. As described above, high-speed aluminum catamarans are widely used as vehicle and passenger ferries. The size-speed relationship of HSS near-term catamaran concepts is compared with representative conventional ships and high-speed ferries in Figure 9. The figure shows that only modest increases in speed and ship size are required for near-term HSS missions. The larger, faster far-term catamaran concept designs are not shown since design studies have shown displacement, installed power, and fuel consumption of these large ships to be much greater than for other (monohull, trimaran, SES) HSS hulls. Catamaran hulls for these high-speed, long-range missions were found to be uncompetitive.

The U.S. shipbuilding industry has very limited experience designing and building catamarans of the size and speed required for HSS missions. However, the existence of a mature international high-speed catamaran industry and the existence of partnering agreements between U.S. shipyards and foreign an designers/builders results in assured availability of the catamaran technology needed to build near-term catamarans. Resolution of remaining technical issues such as development of designs to ABS High-Speed Craft Rules at the sizes of interest, completion of training and technology transfer efforts between foreign builders and their U.S. partners, and adaptation of DNV High-Speed Light Craft Rules-based high-speed ferry designs to meet the more stringent military requirements should result from ongoing commercial development. Consequently, investment in catamaran technology is not recommended.

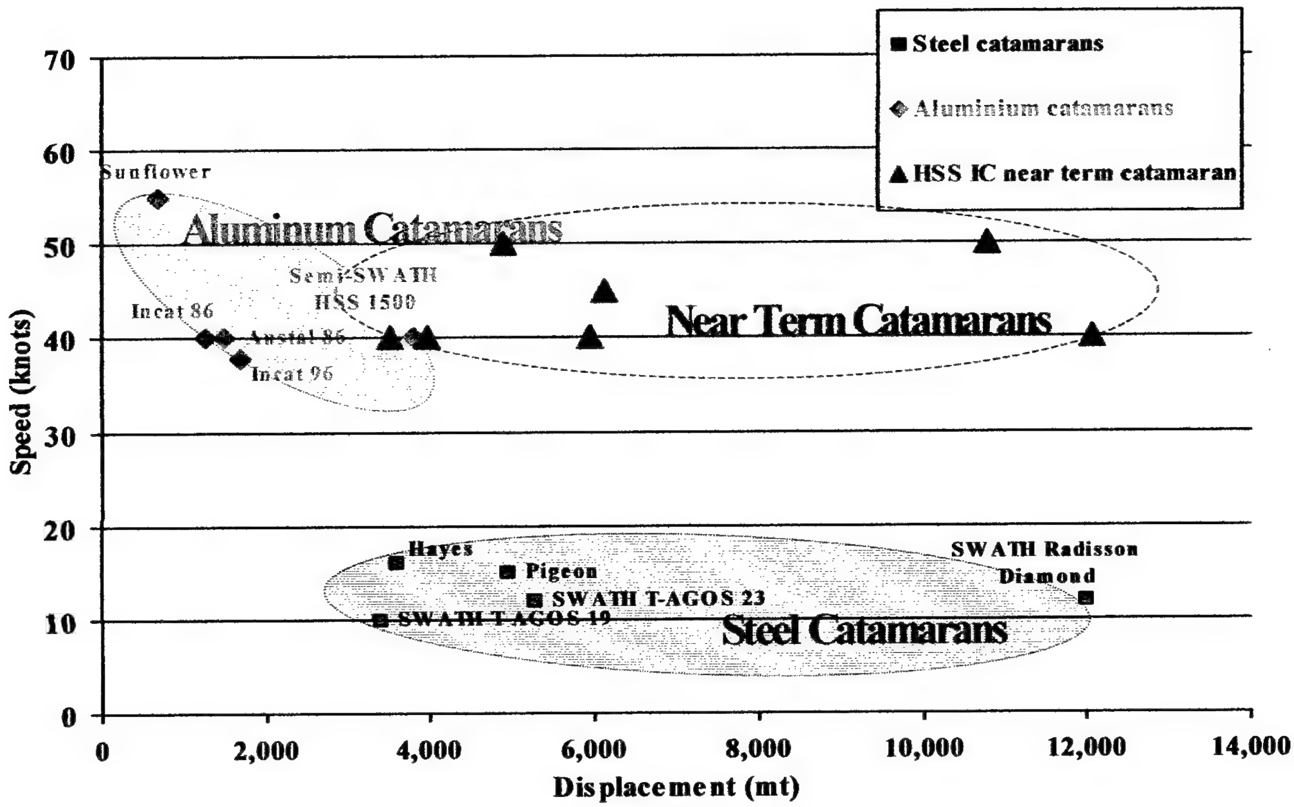

Figure 9 Catamaran Technology

SES. The SES has approximately 40 years of developmental and operational experience in the U.S. and abroad. As a cornerstone of Admiral Zumwalt's 100-knot navy, the U.S. Navy completed a design and intended to construct a high-speed (80-knot), transoceanic, 3,000-ton, low length/beam (L/B) ratio, SES Frigate (3KSES). This aggressive acquisition program evolved from a technology base that included model tests, analysis, and operation and testing of a series of small manned test craft. While the 3KSES program was terminated prior to the construction phase in 1979, a firm SES technology base resulted from the effort.

Significant development of SES technology has occurred as a result of international programs as well. In 1990, the Soviet Union commissioned the largest SES to that time, the 1,000-ton Dergach. The SES size boundary was extended again in 1994 when the 54-knot Japanese Techno-Superliner TSL-A70 was built with a displacement of 1,500 tons. A 700-ton SES test craft underwent detailed development in the Federal Republic of Germany in cooperation with the U.S. However, the project was cancelled before construction began. While this experience augments the U.S. technology base, a significant jump in technology is needed to bridge the gap between these ships with displacements below 1,500 tons and the 20,000-ton HSS SES concepts as shown in Figure 10.

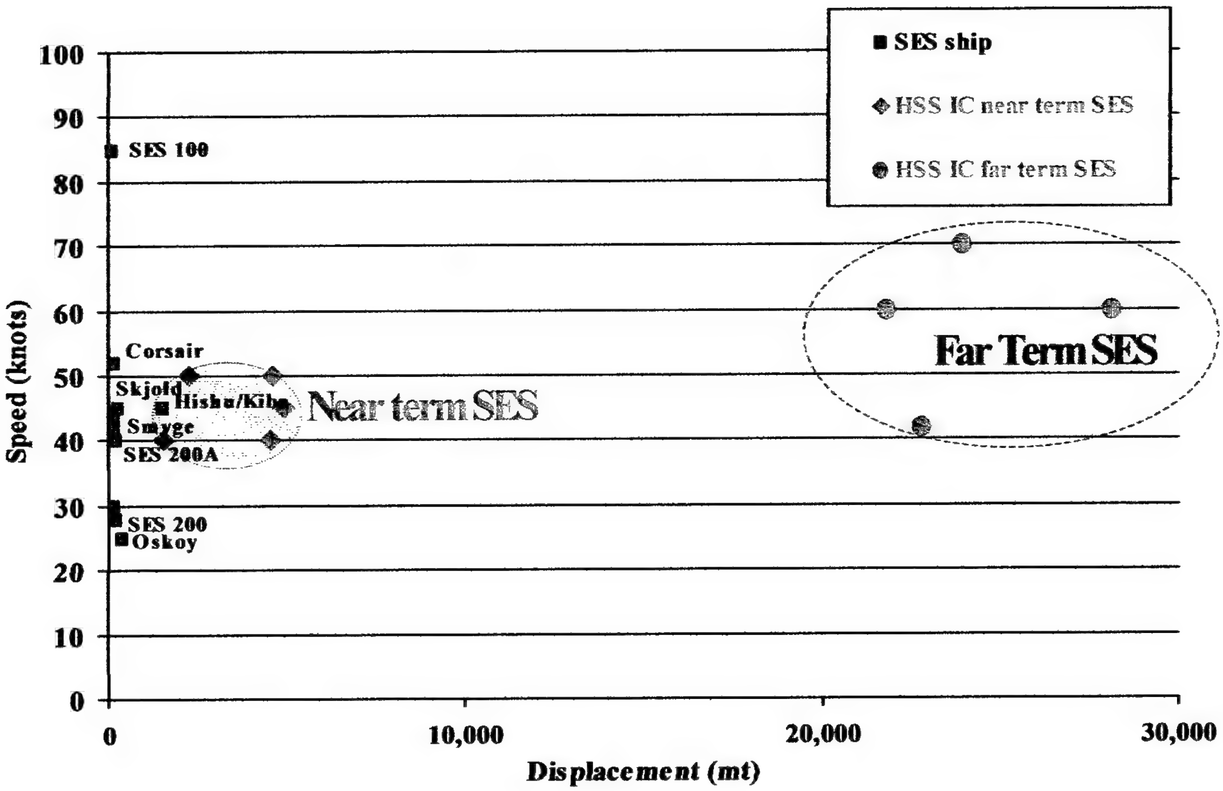

Figure 10 SES Technology

The goal of the process defined by the 1997 High-Speed Sealift Technology Workshop was to determine the technology development requirements to support projected high-speed sealift requirements. Prospective mission requirements were provided by the operators and ship concept designs for those missions were developed by the HSS Innovation Cell. The following section discusses the critical technologies required to realize these HSS ship concepts. These same critical technologies are also required to realize high-speed warship concepts with these types of advanced hull forms.

8. CRITICAL TECHNOLOGIES FOR HIGH-SPEED NAVAL SHIPS (extracted from [2])

Powering. Resistance estimates for the HSS monohull, catamaran, and trimaran designs rely heavily on systematic series model test data such as Series 64 and Taylor Standard Series. Hull form geometry of HSS hulls ($L/\nabla^{1/3}$, section shapes, transom size, bow shape, etc.) differs markedly from the hulls in these standard series. For example, hulls for traditional high-speed ships (e.g. SS United States, SL 7, aircraft carriers, surface warships) and large cargo ships (LMSR, T-AKR 287, T-AKR 5069) have slenderness values below $L/\nabla^{1/3} = 8.0$. By comparison, HSS displacement hulls range between $10 < L/\nabla^{1/3} < 12$. Such differences have significant effect on hull resistance, hull/propulsor integration, and powering requirements for high-speed displacement ships. While limited proprietary data exist in the form of model test and design data associated with development of a few commercial concepts, a comprehensive database to support development of these much more slender hulls is not publicly available. The absence of appropriate systematic series data has forced designers to resort to advanced computational fluid

dynamics (CFD) techniques to address critical powering needs such as resistance of unusual hulls and flow characteristics (bulbs, waterjet inlets, transoms, streamlines over hulls). More challenging is the need to model the flow about a hull with operating high-power waterjets, an essential step toward optimal hull/propulsor integration for peak power and fuel efficiency. However, these analytical methods require careful correlation with physical data to assure accuracy. These test data are not readily available for slender HSS displacement hulls at the high speeds of interest. Absence of these data is a severe obstacle to the development of mission-specific designs and also hinders generic high-speed hull research and design tool development.

Hull/Propulsor Integration. Current practice for designing waterjet-propelled hulls is to first design a hull with low drag followed by the design of waterjets with good propulsive efficiency. Waterjet influence on the hull design is minimal, consisting primarily of geometric requirements for the fit of the machinery and inlets. Conversely, waterjet design is influenced by the hull. Flow irregularities in the waterjet inlet are major factors in the design of waterjet components such as inlet ducts, stators, and rotors. Omitted from the hull design process are the changes in hull flow properties resulting from operation of the waterjets. These changes result from alteration of the pressure distribution near the stern caused by waterjet inlet suction under the hull and exhaust behind the transom. Resistance, sinkage, trim, and the direction of the streamlines over the hull are affected. The draw-down of the water surface in the vicinity of the waterjet inlets is of particular concern since it increases the likelihood of air injestion by the waterjets in a seaway. While pertinent to the design of all waterjet-powered designs, the importance of these flow changes is magnified by the slender hulls and high installed power of HSS concepts. Potential consequences of this lack of integration include reduced efficiency of the waterjet, higher fuel consumption, and operational limitations in waves. Extension of existing design tools, including CFD techniques, as well as the model test techniques needed to validate predictions are critical needs.

Seakeeping. A robust capability for evaluating seakeeping performance of monohull displacement hulls is currently available. Fundamental to this capability are frequency domain computer models based on thin-ship theory that assess the statistical properties of ship motions. Supporting this statistically-based frequency domain foundation are the more complex time-domain programs that predict actual motions of a ship in a specific wave system. These readily available and widely used programs are well validated for conventional monohulls. HSS displacement monohulls are more slender than conventional ships, incorporate different shapes, and operate at higher speeds (or Froude no.- Fn) than current monohulls. While these hull form features are expected to be compatible with current seakeeping tools, validation with test data for representative slender HSS hulls at Fn of interest will enhance credibility. Seakeeping assessments of high-speed, slender displacement catamarans and trimarans are more complex than for monohulls. While the fundamental physics of multihull motions are the same as for monohulls, experience with multihulls such as SWATH ships and slow-speed conventional catamarans has shown that multihulls require significant extensions to monohull seakeeping technology to accurately model non-monohull features such as between-hull interactions, differences in damping, and above-water geometry. Furthermore, the more limited demand for multihull motions prediction capability has inhibited development of ship motions tools for these hulls. While prediction capability exists for catamarans, extension of the tools to more accurately model the hull geometry and hydrodynamic effects of high-$L/V^{1/3}$ HSS displacement catamarans and trimarans is needed. Additional test data are also needed for representative HSS hulls to guide and validate these extensions.

Maneuvering. The technology to predict the maneuvering and dynamic stability characteristics of displacement hulls is well established. The approach used requires solution of generic equations of

motion formulated with empirically or experimentally-derived hydrodynamic coefficients. The resulting system of equations can then be analyzed to assess conformity with U.S. Coast Guard, Code of Federal Regulations, and classification society requirements. While the equations of motion are general, the hydrodynamic coefficients are hull form specific. However, little hydrodynamic data exists for the slender, high-speed, steerable, waterjet-equipped monohulls and multihulls envisioned for high-speed sealift application. Existing displacement hull maneuvering tools are monohull-based and lack the capability to model multihull geometry and mass properties. Existing regulatory body requirements are heavily biased by the characteristics of slower, less slender monohulls. Structural requirements and crew ride quality considerations often result in these conventional ships reducing speed in higher seas. This combination of current standards and operating practices results in assurance of adequate maneuvering and control authority to assure safe operations for the ship loading conditions, speeds, and sea conditions encountered. However, the greater slenderness, higher speed, large draft variations, and control systems envisioned for HSS displacement hulls may result in development of unstable dynamic behavior modes that do not occur for the more conventionally-designed and operated hulls. Furthermore, the premium attached to speed of HSS ships will encourage maintaining high speeds in high seas. Systematic evaluation of high-speed slender HSS hulls to assess the possible existence of undesirable stability characteristics in calm water and in waves has not been done. Consequently, while the methodology to analyze maneuvering and control of HSS displacement ships exists, tool extensions to encompass multihulls, additional hydrodynamic data, and analysis are needed to assure safe operations of HSS concepts throughout the operating envelope.

Seaway Loads. Slam-induced whipping (a dynamic component that increases the vertical and lateral bending moments along the length of the ship) is exacerbated by speed and, in some cases, can approach the magnitude of the wave-induced moments. All of the primary hull girder moments increase in proportion to the square of the length of the ship. There are a number of analytical tools available for predicting seaway loads for conventional monohulls. SMP95 is a linear strip theory code in the frequency domain that gives good results for the wave-induced portion of hull girder bending, but is not applicable for whipping effects. QLSLAM, DYNRES, and LAMP are time-domain codes that have the potential for including whipping in hull girder bending, but all are limited in one way or another. SLAM-2D can predict bow slam pressures. All of the analytical codes were developed for conventional monohulls and have limited validation. Extension of this conventional monohull technology is needed to address the greater slenderness and higher speeds of HSS monohulls. Additional extensions to the technology are required to model geometry and mass properties of HSS trimarans and catamarans. Model test data are required for HSS displacement hull concepts to guide development of the analytic models and validate the predictions. They need further validation (and possibly modification) for applications to novel hull forms.

Low Cost, Lightweight, High Strength Structures. Since the structural weight of a ship is a large part of its displacement, the potential payoffs in weight savings are substantial, in the thousands of tons for large ships. To realize these weight savings, a significant research and development effort is necessary to resolve a number of issues. Projected weight savings and corresponding deadweight density increases are shown in Figure 11 for near and far-term high-speed sealift ships and compared with that of existing ships. Large conventional monohull ships are predominantly constructed of steel, while smaller weight-critical vessels (under 130 meters) are frequently constructed of aluminum or composites. Similarly, steel is the material of choice for many larger SES concepts. However, most of the smaller SES constructed to date have used aluminum as their basic structural material. Weight-critical ships frequently use aluminum material to reduce weight because it has one-third the density and modulus of steel and a fatigue allowable stress one-half that of steel. At a first level approximation for ships governed by hull girder

bending (ships over 130 meters long), aluminum can save one-third of the structural weight of a steel vessel. There are no technical reasons why large ships cannot be fabricated from aluminum, but consideration must be given to the relatively low fatigue characteristics of aluminum and the large deflections that aluminum structures exhibit compared to steel structures. However, the cost of aluminum is five to eight times more expensive than that of steel, and aluminum has a relatively low resistance to fire. Many ships are constructed of high-strength steels or use high-strength steels in certain locations. Some of the high-strength steels are twice as strong (yield strength) as ordinary steel, yet they do not save much weight in large ships. The reason is that structural details composed of high-strength steels have almost the same fatigue allowable stresses as ordinary steel, and, hence, these ships require just as much material to resist hull girder bending. The extra strength can only be used to resist secondary loads. The improvement in the fatigue characteristics of high-strength steels is necessary to significantly improve the structural weight fraction. Composite structures consist of fiber reinforcements (such as E-glass or carbon) encapsulated in a resin matrix (such as vinyl ester or phenolic). Composite materials can be used to produce single-skin, stiffened, or sandwich structures. They have been used for primary structures on small craft or vessels for many years. They are also applicable for secondary structures such as decks, foundations, doors, hatch covers, enclosures, deckhouses, stacks, and masts. In the struggle to develop a low-cost, high-strength/lightweight material, several obstacles remain. Stiffness and fire performance are issues that must be addressed. Effective repair procedures that ensure structural integrity must also be developed. Material development costs can be significant and consideration must be given to production-mode acquisition costs. Many of the materials require strict environmental control during fabrication, requiring significant capital investments in infrastructure development.

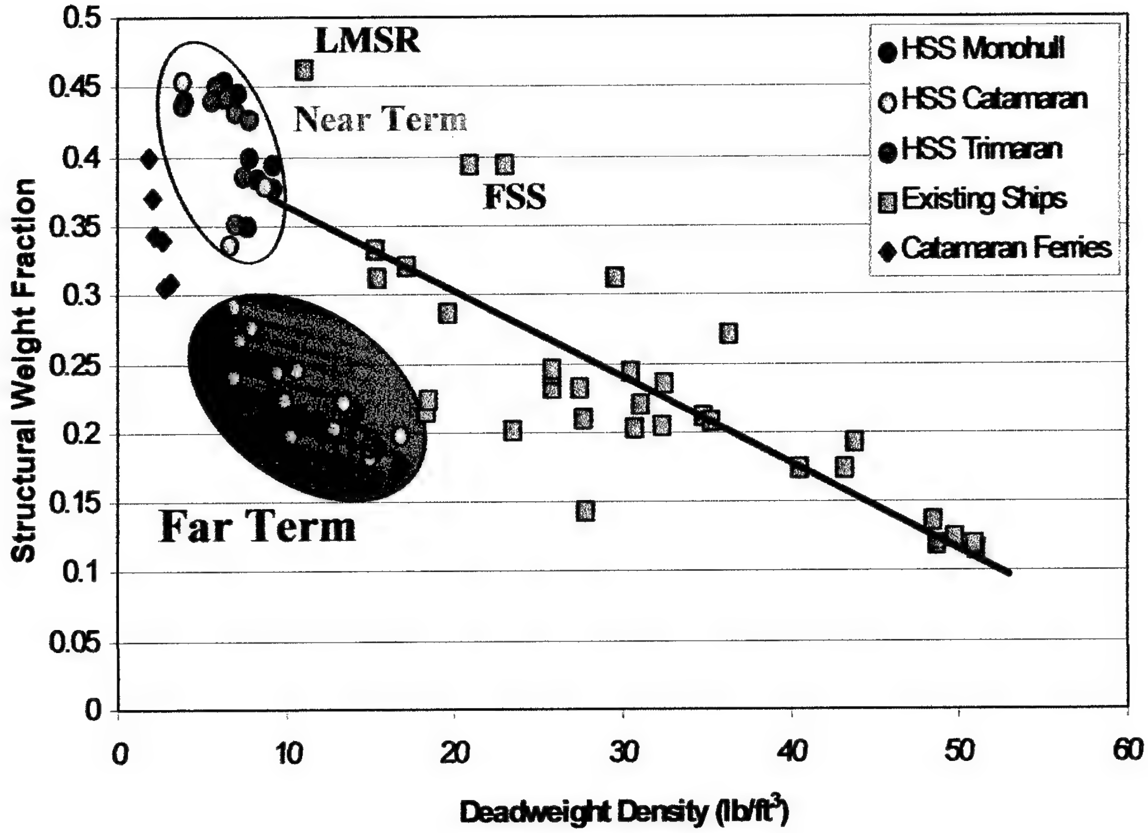

Figure 11 Structural Weight Fraction versus Deadweight Density

Conventional composite fabrication processes are critical in quality control. Because of this issue, new fabrication processes such as vacuum-assisted resin transfer methods (VARTM) have been developed to provide more consistent quality control from part to part. However, variability in material properties continues to be an issue and is highly dependent on the manufacturing process selected. Worker skill also continues to play a significant role in the quality and consistency of the resulting composite material. Further research and development is needed to develop low-temperature, low-cost/high-quality manufacturing processes and fiber/resin combinations that minimize material property variation and maximize strength and stiffness characteristics.

Although stiffness is not as critical for secondary structures or for primary structures when the ship length is less than 130 meters, when the hull length starts to exceed 130 meters, stiffness becomes more of a concern for virtually all of the non-steel material options currently under consideration. For the primary hull structure of large ships, the limited stiffness of non-steel materials can yield a large hull deflection, which may be problematic for critical alignments. Maintaining hull girder stiffness may be required to avoid hull resonance issues such as springing and whipping. In the near-term, E-glass and carbon composites are effective in reducing weight in secondary structures, but they have a low stiffness for the primary hull structure bending in large ships (over 130 meters). In the long-term, carbon fiber improvements or more exotic fibers will provide increased stiffness to composite materials. Furthermore,

advanced hybrids of composite and metallic materials may be applicable for primary structure of large or very large ships (over 300 meters).

Fatigue characteristics must be improved with many of the material options. The fatigue limitations of aluminum and high-strength steels result from their as-welded properties. Improved welding methods (or eliminating welding by adhesive joining methods) can increase the fatigue allowable stresses for both aluminum and high-strength steels. For example, flush ground welding of aluminum increases the fatigue strength to two-thirds that of ordinary steel, resulting in a fifty-percent structural weight saving. Weight savings for high-strength steels would be proportional to any increases in fatigue allowable stresses from advanced welding/ joining techniques. Such advanced welding and joining techniques need to be investigated and developed, and are certainly possible in the far-term.

Propulsion Systems. Significant extension of machinery technology is required to meet the needs of HSS ships. Propulsion machinery must be compact, lightweight, and fuel-efficient, yet produce and transmit very high levels of power. The technical experts at the HSS Technology Workshop identified the types of propulsion machinery components (gas turbines, reduction gears, and waterjets) to meet HSS needs. However, power, weight, and efficiency requirements exceed current capabilities for each of these components, particularly for the far-term ship concepts. Prime movers for HSS concept designs range in power from small current technology turbines producing about 10 MW, to large far-term turbines producing about 100 MW. Existing gas turbines with ratings of up to 30 MW are adequate for a number of the HSS missions, particularly those intra-theater missions with limited range, lower speed, and modest cargo. Progressively more powerful, more fuel-efficient turbines are needed as speed, range, and payload increase. The concept designs show requirements for a near-term nominal 43 MW turbine and a far-term nominal 90 MW turbine. While fuel efficiency is important for all turbines, it is particularly important for the 90 MW turbine since these large turbines are associated with the higher speed, long-range inter-theater missions. Significant gas turbine technology development is required to meet power and fuel consumption goals for missions requiring large near and far-term technology turbines.

The specific fuel consumption rate and power of existing and developmental gas turbines is compared with HSS near and far-term goals in Figure 12. The figure shows that near-term goals can largely be met by marinized LM6000/Trent engines. Far-term gas turbine objectives require development of a turbine like the LM9000 to meet power objectives, as well as significant reduction in fuel consumption. Improvement of gas turbine specific fuel consumption can be realized through two approaches. One is through development of high-temperature materials for the gas turbine, along with gas turbine technologies like advanced blade designs. Studies indicate that this approach would yield a reduction of approximately 10-12 percent, marginally less than the far-term objective. The other approach is through development of intercooling and recuperator (ICR) systems for the larger engines. Projections for the WR21 ICR system currently being developed in the 25 MW power range indicate that use of similar technologies to the larger engines would meet far-term HSS requirements.

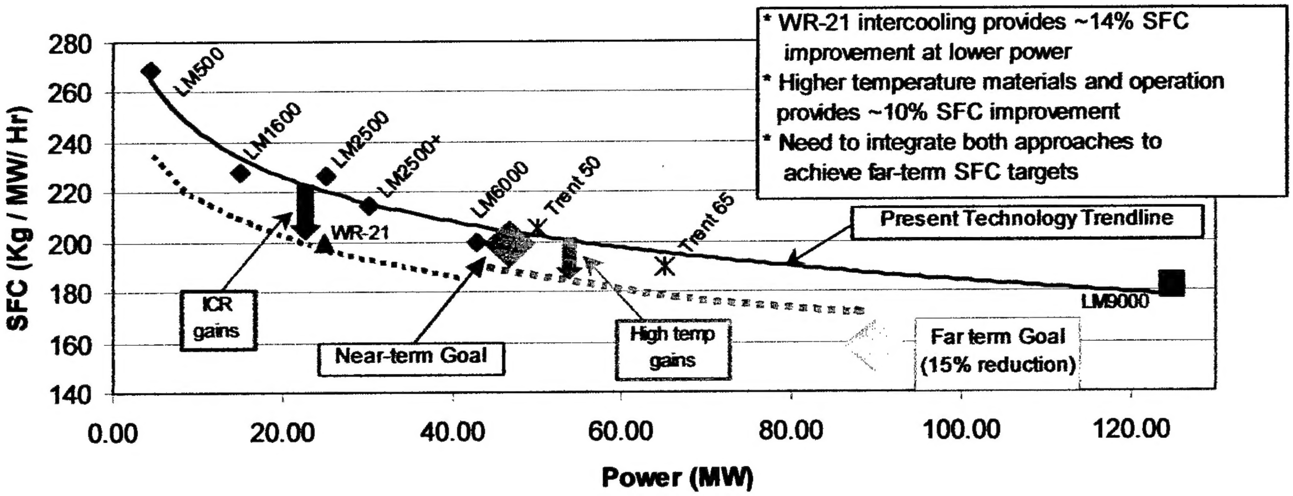

Figure 12 Marine Gas Turbine Technology

Waterjets. Waterjet propulsion is the preferred propulsion system for large, very high-speed HSS vessels. To date, the market for waterjets has been dominated by small ships and fast ferries. Large, high-speed ocean-going vessels will require large amounts of power to be transmitted to the waterjets for propulsion. To keep the number of waterjets per vessel to a reasonable number, waterjets that can absorb up to several times the maximum power of today's most powerful waterjets will be required. The power rating and design speed of existing and developmental waterjets is compared with the pumps needed for HSS near and far-term designs in Figure 13. The figure shows that both near and far-term power goals significantly exceed the power capacity of existing waterjets. Furthermore, while some near-term HSS designs are compatible with mixed-flow waterjets, many near-term and all far-term term designs require the reduced diameter of single-stage or multi-stage axial pumps to fit machinery in the slender hulls. The development of waterjet technology is evolutionary in nature. As a result, the approach would be based initially on advancing the axial waterjet technology from today's 10-13 MW size pumps to the 43 MW near-term pumps. This near-term technology would then be the basis for subsequent evolution of the 100 MW far-term waterjets. Larger, higher power axial-inducer waterjets have not been pursued in recent times, and renewed development of this promising technology has high potential payoff. A near-term waterjet design for the 43 MW gas turbine is the next step in the state-of-the-art for axial-inducer waterjets. The technology needed to manufacture a pump optimized for the 40-50 knot design speed range would be produced. This represents an increase in axial-flow waterjet powering of about three times the present demonstrated capability, and would result in a unit with an impeller diameter in the likely range of 2.5 to 3.5 meters, slightly larger than the 1.8-2.0 meter impellers currently being manufactured for mixed-flow pumps. A 4-year development cycle is required to produce the full-scale near-term pump prototype. The far-term waterjet would be aimed at ships having speeds in the 50-70 knot range. To provide the requisite thrust for a ship of meaningful ocean-going size would require huge amounts of propulsive power. Waterjets capable of absorbing 90 MW of power would be required. Although the amount of power transferred would be double that of the near-term design, relatively small changes in waterjet size would result. As a consequence, the waterjet would become very power dense, with increasing design ship speed exacerbating mechanical and structural design challenges.

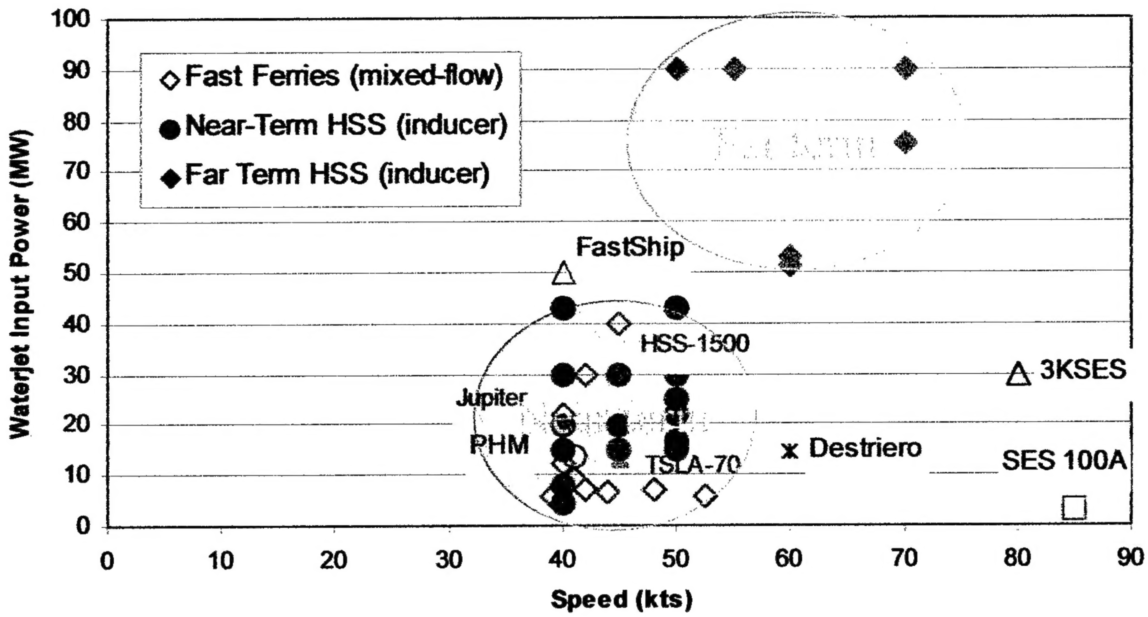

Figure 13 Waterjet Technology

Reduction Gears. The weight of reduction gears represents a significant portion of the total ship weight due to the high installed power required for high-speed sealift ships. Technology development is required, as simply scaling-up existing designs to the desired power levels results in high weights. HSS designs use either a type of offset gear known as a locked-train double-reduction gear or epicyclic gears to transmit power from gas turbines to waterjets. The reduction gears are generally of the single-input, single-output type. All gears are non-reversing. Offset gears are the most widely used type of gear for ship propulsion. The epicyclic gearbox, on the other hand, is not widely used at sea. The epicyclic gearbox provides a very high power density (i.e., it is smaller than the offset gear) and typically weighs less as well. The primary disadvantage of the epicyclic gear is its increased cost relative to the offset gear. During the development of the near-term and far-term HSS concept designs, both types of reduction gears were used. As a result, requirements for two separate development paths presently exist, as no gearbox of either type exists that fully satisfies the reduction gear requirements established by the designs. Near-term goals for both gearbox types are for lightweight designs capable of transmitting between 45 and 50 MW, while the far-term power requirement is 90 MW output. Reduction gear weight is heavily influenced by the input power level, torque and reduction ratio. Figure 14 shows gearbox performance against power level for existing gears and HSS designs. Performance is represented as weight per 'torque', where 'torque' is simply the power divided by the output rpm. The HSS designs represent estimated design weights resulting from the final combination of gas turbine input power and speed and the design speed of the waterjet. Also shown on the curve are estimated trend lines for both offset and epicyclic gears. The principal focus for development for both offset and epicyclic marine gears is reducing the weight to the target levels. In terms of power output, similarly-sized gears have been built, if not for marine propulsion, at least for hydroelectric use. However, these existing designs are much heavier than what the fast sealift high-speed ship designs require. Therefore, significant effort, principally in materials development, is required if the goals are to be met. Materials improvement relates to the use of stronger and lighter materials as well as the manufacturing processes required to make the use of these materials possible. However, the current ability of gear manufacturers to produce gears of very high

dimensional accuracy and surface tolerance is such that it is unlikely that any significant improvements will be made without potentially very large investments.

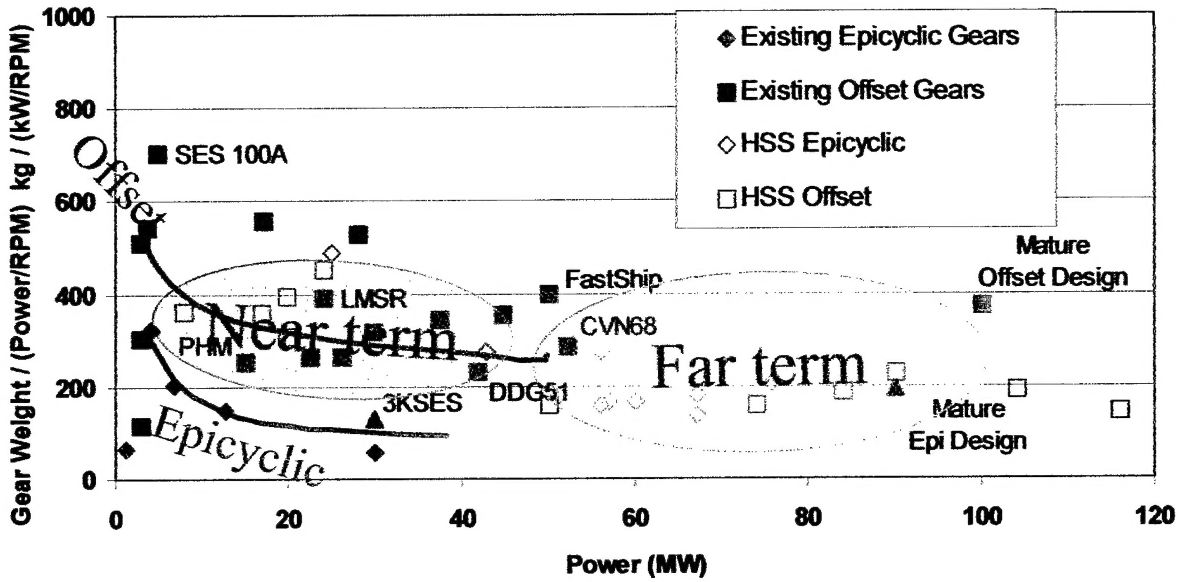

Figure 14 Reduction Gear Technology

9. SUMMARY

NAVSEA's *ship design organizations have produced a wide range of ship concept designs for projected* missions of interest to the U.S. Government in order to assess technology development requirements. Results from these concept design studies have shown that monohull, catamaran, trimaran, and SES hull forms are viable alternatives. However, monohull, trimaran, and SES variants were shown to offer superior weight, power, and fuel consumption advantages for missions resulting in displacements exceeding 10,000 tonnes. Most of these missions are inter-theater, have speeds of 50 knots or higher, and rely on far-term technology. For example, a significant jump in technology is needed to bridge the gap between existing SES ships with displacements below 1,500 tons and the 20,000-ton HSS SES concepts. Therefore, the technical risks in extrapolating current hull forms to meet the more demanding high-speed missions need to be reduced significantly through design, construction, and technical validation of large prototypes of these advanced hull forms. In contrast, catamaran hulls were found to be attractive options for the smaller logistics ship sizes. These intra-theater logistics missions require near-term technology and typically had speeds below 50 knots. Consequently, investment in catamaran technology is not recommended [6]. Several of the plans for development of individual technologies involve significant increases in scale from current technology levels. For example, near-term waterjets will require absorption of over twice the power of today's largest waterjets, while far-term power requirements are four times current levels. Comparable increases in scale exist for advanced structures, gas turbines, and reduction gears. Validation testing of large-scale specimens of these advanced technologies needs to be done in order to reduce technical risk to levels suitable for ship construction. That requires major changes in the Navy's research and development (R&D) investments.

10. THE WAY AHEAD

Sea Power 21 provides a clear vision for sea power in the 21st Century. High-speed ships and craft are crucial to realizing this vision. The U.S. Navy's technical community has clearly identified the critical technologies, the necessary investments and the timelines that are required to develop high-speed ships and craft with increasing levels of speed, payload and range. Given today's state-of-the-art in these critical technologies, advancements can be made in new naval ships with increased speed, payload and range. The Navy is moving out on many of these advancements. However, to accomplish a more complete transformation of the Navy to fully realize the Sea Power 21 vision for future naval warfare, we as ship designers need to enter into intense dialogues with naval operators and understand their vision for future naval warfare. CISD is a very effective forum for such constructive dialogue where operators can focus on specific mission capabilities needed, the Navy's technical community can develop integrated investment strategies for critical technologies, industry can get a better understanding of the Navy's needs and be better prepared earlier in the product development process, and academia can marshall its resources earlier to provide the required people and tools. Such is the formula for transformation: a top-down process involving enterprise-wide senior leaders quantifying issues, developing high-level models and frameworks, and defining enterprise-wide change levers. R&D investment decisions need to be made now, long before the Navy begins to design the truly transformational naval ships of the future. CISD is already serving as a transformation agent by SETTING THE HIGH-SPEED SHIP TECHNOLOGY ROADMAP FOR SEA POWER 21.

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